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Size Variability of Juvenile (0+ Yr) Bay Scallops *Argopecten irradians irradians* (Lamarck, 1819) at Eight Sites in Eastern Long Island, New York

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Abstract. Size frequency distributions of juvenile (0+ yr) bay scallops *Argopecten irradians irradians* were examined at eight sites in eastern Peconic Bays, Long Island, New York, USA, with the specific goal of quantifying the prevalence of small juveniles (≤ 20 mm at the end of the first growing season in December). Sampling was conducted with a diver-operated suction dredge between late December 1990–early April 1991 until ≥ 200 individuals were obtained at each site. The non-normal, negatively skewed size frequency distributions, as well as scallop densities (range: 5.6–21.5/m^2), differed significantly between sites. Shell heights of the 1773 sampled scallops ranged from 7–61 mm; median sizes ranged from 44–52 mm. Small juveniles composed between 0–8.7% of the different populations. Comparative sampling at two of the sites in summer 1991 showed equal or significantly higher survival of small juveniles from winter to summer, relative to larger individuals. The high prevalence of small juveniles during some years, and evidence from the literature that many of these individuals survive to spawn in their second year, compared to the typical semelparous reproductive pattern, suggest that small juveniles may be important to the persistence of bay scallop populations in certain years.

INTRODUCTION

The bay scallop *Argopecten irradians* (Lamarck, 1819) is an important commercial and recreational species along the Atlantic and Gulf coasts of the United States. Bay scallops are hermaphroditic and generally regarded as semelparous, although Belding (1910) estimated that up to 20% of a given year class of the northern subspecies *A. i. irradians* may survive to spawn in two successive years if not removed by the fishery. Spawning of *A. i. irradians,* which is found naturally from Massachusetts to New Jersey (Abbott, 1974), primarily occurs between late May to early September (see review by Barber & Blake, 1991) but may occur as late as November (Tettelbach et al., 1999).

Following larval settlement, shell growth of *A. i. irradians* in natural populations usually averages ~10 mm/month until first season growth ceases around late November/early December (Belding, 1910; Kelley & Gieg, 1981; Tettelbach, 1991). By this time, mean shell height (measured as a tangent from the umbo to the middle of the ventral margin) of these juveniles or "seed" (0+ yr.) is typically 30–55 mm (Belding, 1910; Marshall, 1960, Kelley & Sisson, 1981; Stewart et al., 1981; Tettelbach, 1991).

Occurrence of "small" juvenile scallops toward the end of the first growing season, however, has been reported by several authors. Taylor & Capuzzo (1983) reported evidence of 1–5 mm juveniles in Falmouth, Massachusetts during early November 1979, while bay scallop juveniles as small as 3 mm have been reported in eastern Long Island, New York waters during December of several years (P. Wenczel, personal observation). Kelley & Sisson (1981) concluded that small juveniles predominate in certain populations around Nantucket, Massachusetts, and Kelley (1981) suggested that large scallop harvests in certain areas where no seed was seen the pre-

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vious fall may result from high numbers of small juveniles that go unnoticed. For the present study, small juveniles were defined as individuals ≤ 20 mm in shell height at the end of their first growing season. Assuming a 1–2 week larval period (Loosanoff & Davis, 1963; Tettelbach & Rhodes, 1981) and shell growth of 10 mm/month from the time of larval settlement until the end of November, a 20 mm scallop thus would represent an individual that was spawned in mid-late September (a "late" spawn).

The prevalence of small juvenile *A. i. irradians* and their significance to natural populations remains unclear, probably because the most common methods of sampling (scallop dredges and *in situ* counts by divers) almost certainly underestimate their abundance. The purpose of the present study was to examine the size variability of juvenile (0+ yr) bay scallops at eight different sites in eastern Long Island, New York, USA, using a diver-operated suction dredge, with the specific goal of quantifying the prevalence of small juveniles.

MATERIALS AND METHODS

Sampling of juvenile scallops was conducted between 21 December 1990–1 April 1991, when water temperatures ranged from 3.3–7.8°C. Shell growth of *A. i. irradians* is known to cease when water temperature drops below 45°F (= 7.1°C) and commences in the spring when water temperature reaches 45–50°F (7.1–10°C) (Belding, 1910). Thus, the period between December–early May has typically been reported as the period when no increase in shell growth occurs (Belding, 1910; Helm, 1983; Tettelbach, 1991). In the present study, the size of all sampled seed is considered to be the size they reached at the end of their first growing season.

Scallop sampling was conducted at eight different sites in the Peconic Bay system in eastern Long Island (Figure 1). Sites were chosen on the basis of scallop density, presence of eelgrass, geographical separation, their historical importance as scallop harvest areas, and/or anecdotal knowledge of small or large (≥ 57 mm) juvenile occurrence (the latter are legal to harvest in New York waters). Sampling at each site was done following a preliminary visual inspection of the bottom by divers to determine if eelgrass *Zostera marina* was present and if scallop density appeared to be high enough to obtain 200 juveniles in a reasonable period of time. While the sampling thus does not represent a random cross-section of each of the eight sites, the selection process permitted us to sample as many geographically distinct sites as possible. Sampling was completed over a linear distance of ~150 m at each of six sites, while at Barcelona Neck (B) and East Shelter Island (ESI) this distance was ~250–300 m.

All sampling was conducted with a 160 gpm diver-operated suction dredge equipped with a 5 hp engine and a 5–6 mm mesh collection bag; the effective minimum retention size of the bags was 7–8 mm. A total of 167 haphazardly placed 1-m^2 quadrats were sampled on 16 different days, at MLW depths ranging from 0.7–2.3 m (Table 1). Collection of ≥ 200 seed at a given site required between 1–3 days (Table 1). Preliminary sorting was done on deck, while screening and picking of smaller scallops were done in the lab. Individuals that lacked a clear-cut, raised annual growth ring (Belding, 1910; Marshall, 1960; Helm, 1983) were classified as juveniles. Shell height of all scallops was measured to the nearest mm with calipers.

Retention efficiency of the suction dredge was evaluated on 21 December 1990 through blind sampling trials using marked scallops. Of 115 planted scallops, ranging in height from 14–36 mm, 100% were recovered shortly after they were dispersed into 10 different 1-m^2 quadrats in the eelgrass bed at the East Marion site. During field sampling of natural populations, two byssally attached scallops (< 20 mm) that were observed by divers in quadrats were not recovered from the mesh sampling bag, probably because these scallops were not picked up by the dredge.

Eelgrass density was determined at each site via visual counts of shoots in each of 10 haphazardly placed 0.043-m^2 quadrats. Sampling was completed between 28 March–1 April 1991, although eelgrass shoots persisted through the winter. Eelgrass densities ranged from 353–835 shoots/m^2 (Table 1). A Kruskal-Wallis test (Computing Resource Center, 1992) showed significant differences between eelgrass densities at the eight sites ($\chi^2 = 31.3$, 7 df, $P \leq 0.0001$). Non-parametric multiple comparisons tests (Zar, 1984) were similar statistically, except the Alewife Creek and Sag Harbor sites had significantly higher ($P < 0.05$) eelgrass densities (range:686–835 shoots/m^2) than the West and East Shelter Island sites (range: 353–530 shoots/m^2).

Sampling in July and August 1991 was conducted to determine whether differential mortality of small juvenile scallops had occurred since the winter sampling period. This was done by comparing the proportion of small juveniles present at a given site during the winter versus the proportion of adult scallops in the summer with annual growth rings that were 7–20 mm from the umbo. Large juveniles (> 57 mm) and adults with large rings were excluded from these analyses because in New York the former are legal to harvest in their first winter and thus are selectively removed. Summer 1991 sampling was only conducted at the Greenport and Sag Harbor sites due to: (1) drastic reductions in scallop densities and (2) the passage of Hurricane Bob through the area on 19 August 1991. The latter created extensive windrows of scallops at some sites and probably differential transport of small and larger juveniles.

RESULTS

Overall mean density of 0+ yr scallops during the winter 1990–91 sampling period was 10.62 scallops/m^2. Counts

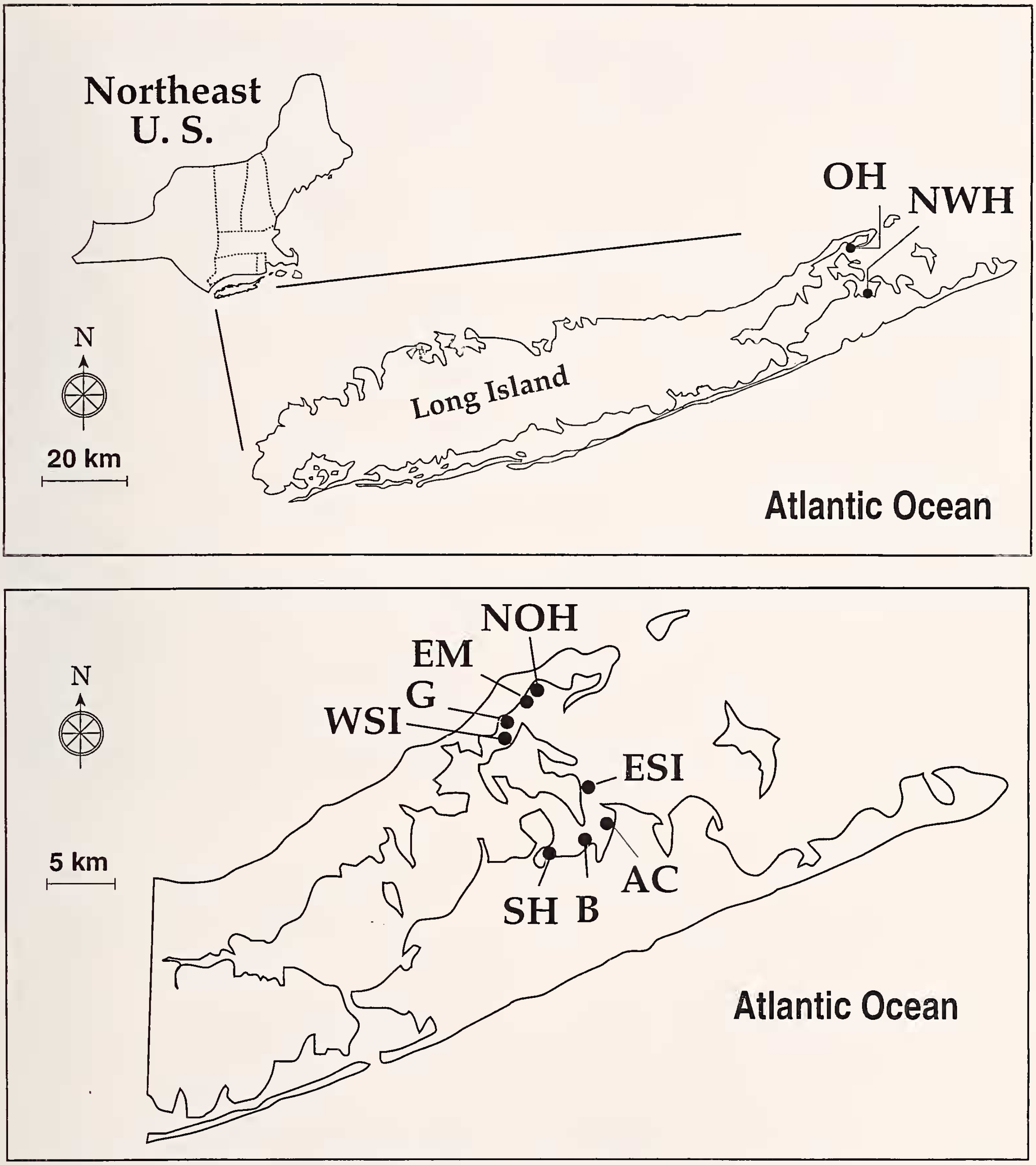


Figure 1. Maps showing location of Long Island, New York in the northeast United States, and location of sampling sites in the Peconic Bay system in eastern Long Island. OH = Orient Harbor, NWH = Northwest Harbor. See Table 1 for sample site abbreviations.

Table 1

Summary of sampling activities and parameters of the eight sites in eastern Peconic Bays, Long Island, New York, USA at which bay scallop size frequency distributions were examined during winter 1990–1991. *The 21 Dec sampling date was in 1990; all other sampling dates are in 1991. Bottom types (in addition to eelgrass): MS = muddy sand, S = sand, P = pea gravel, G = gravel, C = cobble.

Site	Sampling date(s)*	Water temp. (°C)	Depth (m) at MLW	Eelgrass density (# shoots/m²) Mean (SD)	Bottom type	# 1/4 m² Quadrats sampled	# Scallops sampled
N. Orient Harbor (NOH)	29 Jan, 8 Feb	3.3–4.4	1.2–1.5	628 (201)	S, G, C	11	236
East Marion (EM)	21 Dec, 2 Jan	5.6–7.1	1.3–2.0	584 (299)	S	17	224
Greenport (G)	8, 15 Mar	4.4–6.7	1.0–1.5	607 (166)	S	21	229
Off Alewife Creek (AC)	25 Mar	6.1	1.5	835 (123)	S	11	217
E. Shelter Island (ESI)	8, 11, 15 Feb	3.9–4.4	1.7–2.3	530 (158)	S, G, C	31	220
W. Shelter Island (WSI)	29 Mar, 1 Apr	7.2–7.8	1.7–2.3	353 (108)	MS	16	220
Barcelona Neck (B)	18, 26, 28 Mar	5.0–7.8	1.5–2.0	558 (92)	S, P	37	208
Sag Harbor (SH)	1, 4 Mar	3.9–6.7	0.7–1.7	686 (228)	S	26	219

in 1-m² quadrats ranged from 0–45 individuals. Mean densities at the eight sites ranged from 5.62–21.45 scallops/m² (Figure 2). An ANOVA comparing square root-transformed scallop densities was highly significant ($F = 13.89$, 7 df, $P < 0001$). Bonferroni multiple comparisons tests (Computing Resource Center, 1992) revealed that densities at the East Marion, North Orient Harbor, Alewife Creek, and West Shelter Island sites did not differ statistically ($P \geq 0.39$), but that the latter three sites had significantly higher densities than those at East Shelter Island, Barcelona, and Sag Harbor ($P < 0.005$). During summer 1991, mean scallop densities were dramatically lower than in the winter: 1.61 scallops/m² at Greenport (on 24, 31 July, 2 August, and 1.73 scallops/m² at Sag Harbor (on 15 August).

Shell heights of the 1773 seed scallops sampled during winter 1990–1991 ranged from 7–61 mm (Figure 3). The mean and median overall sizes were 46 and 47 mm, respectively. Mean shell heights ($n = 208–236$) at the eight different sites ranged from 42 mm (East Shelter Island and Greenport) to 51 mm (Sag Harbor), while median heights ranged from 44 mm (East Shelter Island) to 52 mm (Sag Harbor) (Figure 3).

The scallop size frequency distributions were all negatively skewed and determined to be severely non-normal via Shapiro-Wilk tests (Computing Resource Center,

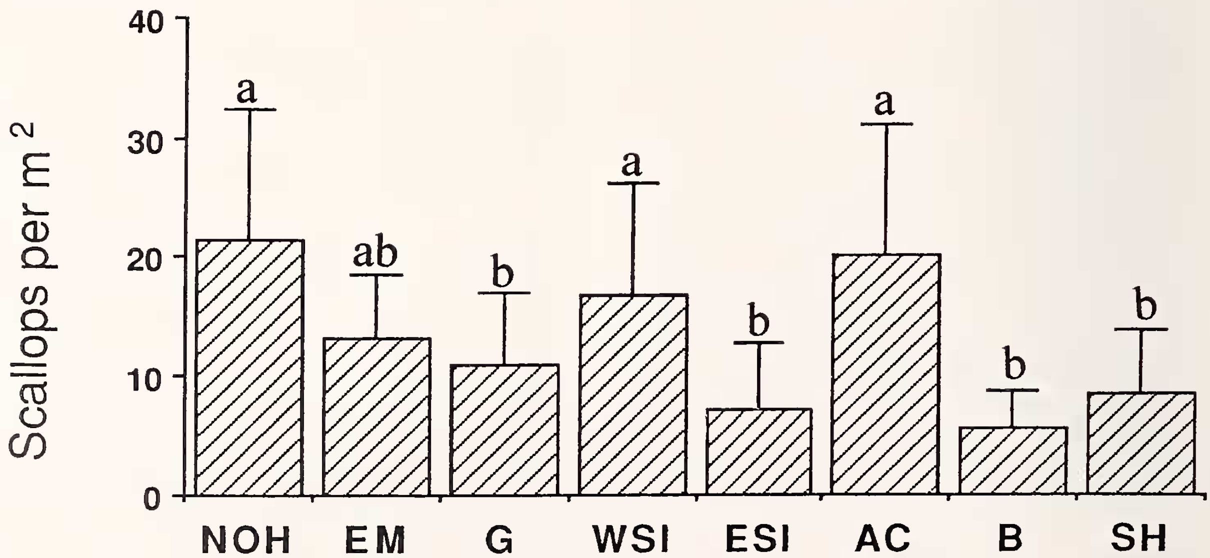


Figure 2. Mean density (+1 SD) of juvenile (0+ yr) bay scallops *Argopecten irradians irradians* sampled via diver-operated suction dredge, at each of eight sites in eastern Peconic Bays, Long Island, New York, USA during winter 1990–1991. Letters (a, b) denote differences in mean density as determined in Bonferroni multiple comparisons tests. See Table 1 for sample site abbreviations.

1992), so non-parametric analyses were necessary. A Kruskal-Wallis test demonstrated that size-frequency distributions at the eight sites (Figure 3) were not equivalent (χ^2 = 404.6, 7 df, $P \leq 0.0001$). Subsequent non-parametric multiple comparisons tests (Zar, 1984) revealed that size-frequency distributions at the West Shelter Island and Sag Harbor sites were not significantly different from each other (Q = 2.80, 8 df, $P > 0.05$), but these size-frequency distributions were significantly different from those at the other six sites (Q = 5.40, 8 df, $P < 0.001$) (Figure 3).

The overall prevalence of small ($\leq$ 20 mm) juveniles in winter 1990–1991 samples was 2.59%; the percentage of small juveniles at individual sites (Figure 3) ranged from 0% (Alewife Creek) to 8.73% (Greenport). A contingency test revealed that proportions of small juveniles at the different sites varied significantly (G = 45.22, 6 df, $P < 0.001$). Subdivided contingency tests (Zar, 1984) showed that proportions of small juveniles at Greenport and East Marion were not different from each other (G = 1.0, 1, df, $P > 0.25$), but these sites had significantly higher proportions of small juveniles than other sites (G = 40.64, 1 df, $P < 0.001$).

The overall prevalence of large (> 57 mm) juveniles in winter 1990–1991 samples was 2.09%; the percentage of large juveniles at individual sites (Figure 3) ranged from 0% (Alewife Creek, East Shelter Island) to 7.3% (Sag Harbor). A contingency test revealed that the prevalence of large juveniles varied significantly between sites (G = 31.58, 5 df, $P < 0.001$). Proportions of large juveniles in the Sag Harbor and West Shelter Island populations were not different from each other (G = 0.56, 1 df, $P > 0.25$), but these sites had significantly higher proportions of large juveniles than other sites (G = 29.58, 1 df, $P < 0.001$).

The relationship between scallop shell height and scallop density was examined via Spearman-Rank correlation tests (Computing Resource Center, 1992) because the size data were non-normal. When data from all eight sites were pooled, the H_o (that scallop density and size are independent) was not rejected (r_s = −0.0423, p = 0.0747). However, because this value was marginally non-significant, data for each site were also examined individually. At seven of the eight sites, scallop density and size were independent ($P \geq 0.13$). At the East Shelter Island site, scallop density and size were related positively (r_s = 0.1553, P = 0.0212).

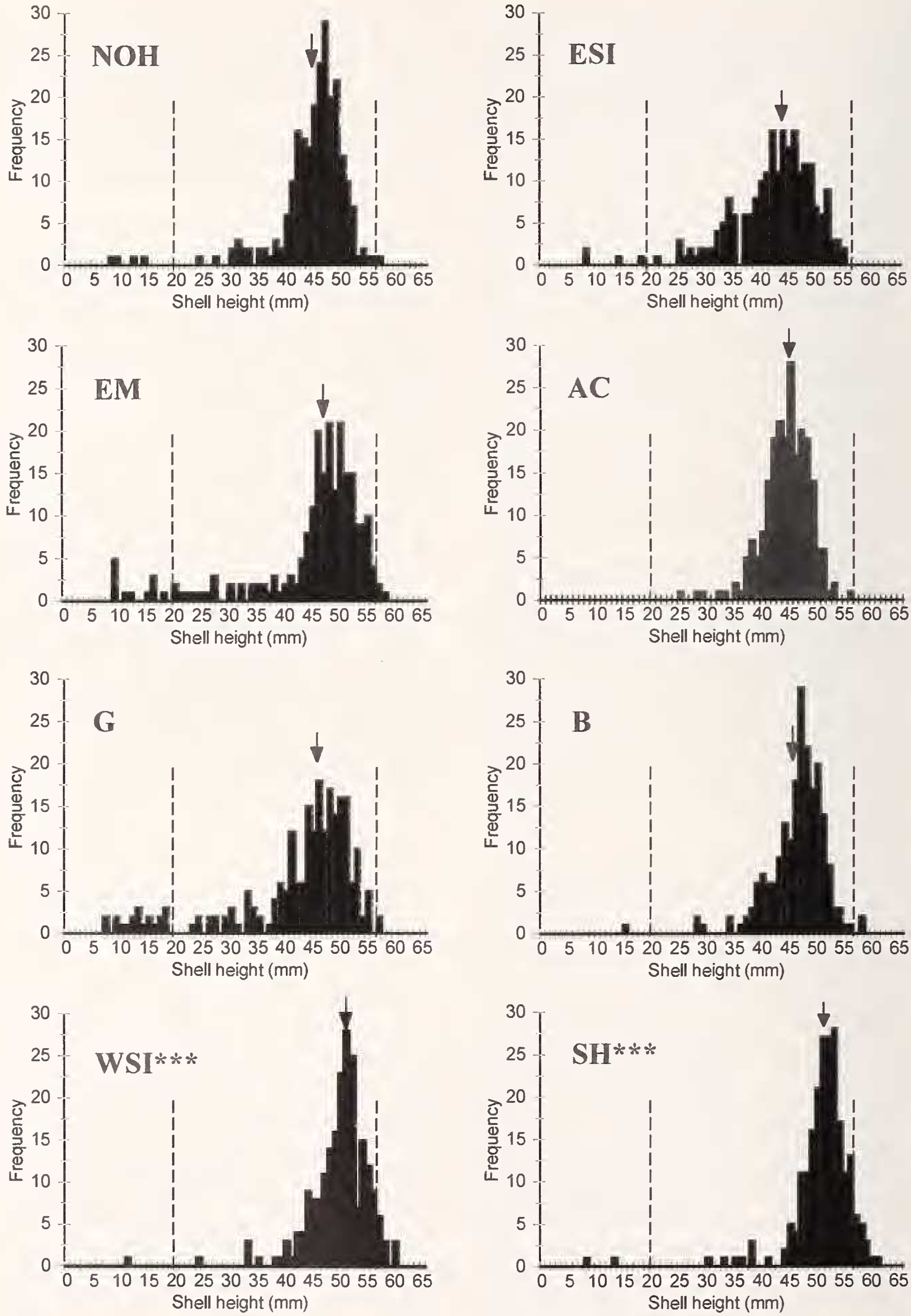
Winter-summer comparisons to examine differential mortality of small juveniles showed variable results. Of the 25 adult scallops sampled at the Sag Harbor site on 15 August 1991, only one had a growth ring < 20 mm. This proportion was not significantly different (G = 1.08, 1 df, $P > 0.25$) from that represented by small juveniles in the winter sample. At the Greenport site, however, where 25 of 85 sampled scallops in late July/early August had annual growth rings that were 7–20 mm from the umbo, these individuals comprised a greater proportion of the summer population (G = 18.96, 1 df, $P < 0.001$) than that represented by small juveniles in the winter population. Seventeen adult scallops with rings between 3–6 mm also were found in the Greenport summer sample, but these were excluded from the comparison because this size range of juveniles was not retained during winter 1990–1991 suction dredge sampling.

DISCUSSION

Our comparison of scallop size variability at eight sites during 1990–1991 reflects an exceptional recruitment event. Local baymen regarded the 1990 bay scallop set to be the heaviest in the Peconic Bay system in recent memory. As compared to the overall mean density of 10.62 juvenile scallops/m^2 (range = 5.62–21.45/m^2) which we observed in winter 1990–91, subsequent suction dredge sampling in 1994 showed that mean density of juvenile scallops $\geq$ 7 mm at the Alewife Creek site on 9 March was 12.8/m^2, while densities in late February/early March at Greenport and East Marion were 2.6/m^2 and 1.6/m^2, respectively (S. Tettelbach, unpublished data).

Estimates of scallop density obtained via suction dredge sampling are likely, in many instances, to be more accurate than those derived from dredging or visual surveys. In late September 1990, visual surveys of 0+ yr scallops at the Alewife Creek site yielded a mean density of 20.7/m^2 (S. Tettelbach, unpublished data), which is comparable to the 20.0/m^2 figure we obtained by suction dredging on 25 March 1991. However, a visual estimate of juvenile scallop density at Alewife Creek in October 1993 ($\leq$ 4/m^2) was much lower than that reflected in suction dredge samples at the site on 9 March 1994 (12.8/m^2). Many factors, including substrate characteristics (particularly the density of seagrasses and other macrophytes), scallop size, water clarity, and the experience of the observer may contribute to lower accuracy of visual censuses, relative to suction dredge sampling.

The size frequency distributions of scallops sampled via suction dredging are also likely to be different from those obtained by dredging or visual censuses. Average sizes of scallops sampled at our eight sites fell in the midst of the reported range of mean sizes of *A. i. irradians* in many previous studies, as obtained via visual sampling by divers or by scallop dredge (Belding, 1910, Marshall, 1960, Kelley & Sisson, 1981; Stewart et al., 1981; Tettelbach, 1991). However, at the Greenport site in September 1991, we determined that scallops $\leq$ 50 mm were significantly less likely to be retained in a bay scallop dredge with a standard bag (with 51 mm [= 2 in] rings), or when fitted with a 27 mm diagonal (3/4 × 3/4 inch square) mesh liner, compared with a suction dredge (G = 28.66, $P < 0.001$). It is likely therefore that average sizes of 0+ yr bay scallops reported in the literature are overestimates of true sizes in populations where small


NOH
ESI
EM
AC
G
B
WSI***
SH***
Frequency
Shell height (mm)
0 5 10 15 20 25 30
0 5 10 15 20 25 30 35 40 45 50 55 60 65

juveniles exist. Even though we sampled seed scallops as small as 7 mm in the present study, it is likely that we still underestimated the prevalence of small seed at some sites. In 1994, when we did suction dredge sampling with a 2 mm bag (S. Tettelbach, unpublished data), one 2 mm juvenile scallop was obtained at Greenport, and 2–6 mm individuals composed 17.8% (8/45) and 8.0% (2/25) of the juveniles sampled at this site in late February and late March 1994, respectively. At East Marion, 2–6 mm individuals composed 6.7% (1/15) of the juveniles sampled in early March 1994. At the Alewife Creek site, however, no 2–6 mm juveniles were found among 204 seed sampled in early March and early April 1994. Summer 1991 sampling at Sag Harbor showed that we did not underestimate the abundance of juveniles < 7 mm in winter 1990–1991, but we clearly did at the Greenport site where there was a high prevalence of adults with annual growth rings < 7 mm from the umbo in our summer 1991 samples.

While we documented scallop densities at eight different sites in 1990–1991, it was beyond the scope of the study to determine how much these densities might have changed during the course of the winter sampling period. Suction dredge sampling in 1994, however, permitted two such estimates. In Wilcoxon rank-sum tests the mean densities of juvenile scallops ≥ 7 mm at the Alewife Creek site dropped significantly ($z = 2.90$, $P = 0.0037$) from 12.8/m^2 on 9 March to 6.3/m^2 on 6 April. Similarly, at Greenport, mean densities of juvenile scallops ≥ 7 mm dropped significantly ($z = 2.39$, $p = 0.0168$) from 2.6/m^2 on 25 and 28 February to 1.1/m^2 on 28 and 30 March. It is not known if these patterns are representative of other years.

While the reasons for the above decline in scallop densities during 1994 are not clear, the dramatic decrease in density between winter 1990–1991 and summer 1991 is likely due to mortality related to heavy infestation of scallop shells by the burrowing polychaete *Polydora* (Tettelbach & Wenczel, 1993). These worms were first noted in January 1991; their density appeared to increase through the winter. Qualitative evidence of worm-related scallop mortality in the form of high numbers of cluckers (empty shells with an intact hinge) was seen in summer 1991 but lacking in winter 1990–1991. This suggests that most of the scallop mortality occurred after the winter period. Worm densities in scallop shells in winter 1993–1994 appeared qualitatively to be much lower than in winter 1990–1991.

No evidence of reduced scallop size over the observed range of densities was seen in this study. Reports of density-dependent effects in scallop populations, however, are common (see Orensanz et al., 1991). Densities at which reduced shell growth of bay scallops was evident in suspended enclosures (Duggan, 1973; Widman & Rhodes, 1991) were considerably higher than in our study. Cooper & Marshall (1963) determined that condition indexes of bay scallops in the Niantic River, Connecticut were consistently lower (although only sometimes statistically different) at a site with densities as high as 65–75/m^2, compared to a similar habitat where densities were ~ 11-25/m^2. They inferred that differences in condition resulted from crowding and competition for food.

All of the size frequency distributions in the present study showed strong negative skewness, with Alewife Creek and Sag Harbor having the least and highest negative skewness, respectively (Figure 3). Several sites showed possible bi- or polymodal distributions, particularly at Barcelona, East Shelter Island, and Greenport. These types of size-frequency distributions may reflect multiple or continuous recruitment events during summer-fall 1990 and/or differential growth or mortality of different scallop sizes or groups. Multiple spawning peaks have been described in several bay scallop populations (see Barber & Blake, 1991). However, determination of the underlying reason(s) for the form of size-frequency distributions in populations is dependent on detailed knowledge of recruitment events determined through a series of samples, rather than a single sample (Ebert et al., 1993).

Small juveniles observed in our study may result from "late" spawning, a prolonged larval period and/or slow growth following larval settlement. Evidence of spawning in the Peconic Bay system during September, October, and November of several years, obtained via histological analyses (Tettelbach et al., 1999), supports the first and possibly the second mechanism. In Massachusetts, Kelley (1981), Taylor & Capuzzo (1983), and MacFarlane (1991) also provided evidence of spawning in September and October of certain years. In the latter two papers, the authors concluded that deeper water populations spawned later than those in shallower water and probably contrib-

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Figure 3. Size frequency distributions of juvenile (0+ yr) bay scallops *Argopecten irradians irradians* sampled via diver-operated suction dredge, at each of eight sites in eastern Peconic Bays, Long Island, New York, USA during winter 1990–1991. *** signify that size frequency distributions at these sites were statistically different ($P < 0.001$) from those at other sites, as determined in non-parametric multiple comparisons tests. Small (≤ 20 mm) and large (≥ 57 mm) juvenile scallop groups are demarcated by dashed vertical lines. Arrows indicate median shell heights at each site. See Table 1 for sample site abbreviations.

uted to the appearance of small seed in certain populations. Interestingly, the Greenport and East Marion sites, which had the highest proportions of small seed in this study and historically are known by baymen to be areas where small seed are often found, are located near a channel off NW Shelter Island where deep water bay scallop populations exist. Duration of the larval period of scallops is known to be prolonged at low water temperatures (Belding, 1910; Tettelbach & Rhodes, 1981; Cragg & Crisp, 1991). Given that bay scallop spawning in the fall is likely occurring at lower temperatures than in summer, the larval period may well be longer (Tettelbach et al., 1999). Further work is needed to elucidate which of the above mechanisms is most important in affecting the occurrence of small seed in winter populations.

Winter-summer comparisons to examine differential mortality of small seed at Sag Harbor and Greenport showed that small seed had an equal or lower rate of mortality than larger sizes, which is different from what might be expected on the basis of the relative susceptibility of the different size classes to crab predation (Tettelbach, 1986; Streib et al., 1995) and other factors (see Orensanz et al., 1991). Clearly, further study of the survivability of small seed is warranted.

Bay scallop populations are well known for pronounced annual fluctuations in abundance (Belding, 1910; Tettelbach & Wenczel, 1993); we suggest that small juveniles may contribute, or be essential to the persistence of bay scallop populations during certain years. This may be especially important in cases where recruitment failures occur, as has happened during brown tide algal blooms in Long Island, New York waters (Cosper et al., 1987; Tettelbach & Wenczel, 1993). A clear example of the importance of small juveniles is provided by a sample taken on 9 October 1992 at the Alewife Creek site where 100% (n = 268) of adult scallops sampled had growth rings which were 2–7 mm from the hinge (Tettelbach et al., 1999). These individuals were all small juveniles at the end of 1991, a year in which a 1-month brown tide bloom occurred in the Peconic Bays. MacFarlane (1991) determined that 9% of adult bay scallops in Pleasant Bay, Massachusetts in January 1980 had growth rings between 4–8 mm from the hinge; furthermore, ~ 50% of these individuals did not spawn in the ensuing year, but spawned the following summer. Arnold et al. (1998) have suggested that self-seeding may be necessary in order for discrete local bay scallop populations to be maintained from year to year. If a large proportion of small juvenile bay scallops survive to spawn in a second year, as suggested by MacFarlane (1991), these individuals may be particularly important because they may serve to extend the semelparous spawning of the population, and buffer the impact of a single year recruitment failure.

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